Eurasia Journal of Mathematics, Science & Technology Education, 2016, **12**(7), 1881-1907
doi: 10.12973/eurasia.2016.1535a

The Impact of Engineering Integrated Science (EIS) Curricula on First-Year Technical High School Students' Attitudes toward Science and Perceptions of Engineering

Younkyeong Nam
Pusan National University, REPUBLIC OF KOREA
Sun-Ju Lee
Gyeonggi Mechanical Technology High School, REPUBLIC OF KOREA
Seoung-Hey Paik
Korea National University of Education, REPUBLIC OF KOREA

•*Received 26 June 2015*•*Revised 19 January 2016* •*Accepted 21 January 2016*

This study investigated how engineering integrated science (EIS) curricula affect first-year technical high school students' attitudes toward science and perceptions of engineering. The effect of the EIS participation period on students' attitudes toward science was also investigated via experimental study design. Two engineering integrated science curricula were purposefully designed and implemented for the study. Two important results emerged: (1) The EIS curriculum participation period (10 or 18 weeks) mattered in terms of changing students' attitudes toward science and (2) A majority (>61%) of the students from both control and experimental groups who participated in the first EIS agreed that the curriculum positively affected their understanding of engineering practice. The results suggest that EIS is a potential pedagogical approach for reforming current science practice in technical high school programs to improve both students' interest in science and career readiness. Implications for implementing EIS in technical high school settings are addressed.

Keywords: attitudes toward science, engineering integration, engineering perceptions, technical high schools

Correspondence: Seoung-Hey Paik,
Department of Chemistry Education, Korea National University of Education, Gangney Myun, Hungduk Gu, Chungju City, Chungbuk, Republic of Korea.
E-mail: shpaik@knue.ac.kr

ISSN: 1305-8223 http://iserjournals.com/journals/ejmste

INTRODUCTION

Over the last decade, preparing secondary students for STEM (Science, Technology, Engineering, and Mathematics) related careers has been a critical issue in education not only in South Korea but in other developed countries (Yuan, 2004). The executive report to president Park Geun-Hye, *Preparing creative human resources and advanced science and technology for Korea's future* (Ministry of Education, Science, and Technology [MEST], 2010) reflects growing consensus that South Korea's future success depends on the quality of human resources who are prepared to become STEM leaders in the 21st century. MEST (2010) called the new national STEM education effort *STEAM* (Science, Technology, Engineering, Art, and Mathematics) education and emphasized that K-12 education should focus on integration of all STEAM disciplines to prepare creative future leaders in STEM (p. 8). One of the important rationales for this new STEAM education movement was the urgent need to improve South Korean students' interest in STEM, particularly in science (Korea Institute of S&T Evaluation and Planning [KISTEP], 2014). As reported in many international comparison studies, South Korean students' attitudes toward science score much lower than the international average, whereas their science achievement scores have been ranked highest (Korean Institute for Curriculum and Evaluation [KICE], 2013; Organization for Economic Co-operation and Development [OECD], 2009). As a result of the national spotlight on STEAM education as a possible solution to improving students' interest in science, STEAM-integrated science curricula and studies exploring the impact of STEAM integration in secondary science classrooms have dramatically increased over the last five years (Kim & Kim, 2014).

However, the national STEAM education effort in secondary classrooms has focused more on attracting high-achieving students to pursue careers in STEM-related fields (MEST, 2010; KISTEP, 2014). MEST (2010) specifically indicates that raising gifted and talented students as creative STEM leaders is one of three critical tasks for national education reform for a successful future (p.11-12). Consequently, the majority of recently developed STEAM integrated science curricula and studies tend to target high-achieving student groups in general high schools and science-specialized talented and gifted high schools (Choi, 2014). Unfortunately, STEAM integration efforts in low-achieving student groups, such as those in vocational and technical high schools, are largely ignored by science educators (Kim & Kim, 2014).

Technical high schools have been purposefully established and supported by the South Korean government since 1973 in order to train enough technicians to

State of the literature

- In contrast to its internationally high-ranked science achievement, South Korean students' interest and confidence in science is lower than that of students in most developed countries, and this situation is even more pronounced among technical high school students in South Korea.
- Much of the STEM education literature and recent science education reform documents recommend integrating engineering into K-12 science classrooms to improve students' science literacy as well as real-world problem solving skills.
- In much of the engineering education literature, engineering design is considered a useful pedagogical approach to helping students understand disciplinary knowledge and core practices in engineering.

Contribution of this paper to the literature

- The results of this study show that adopting an engineering integrated science curriculum is a useful direction for making school science more interesting and meaningful not only to technical high school students but to all students in South Korea.
- A theoretical framework for meaningful engineering integration into K-12 science classrooms is proposed to provide a guideline to the practical aspects of implementing an engineering integrated science curriculum which would be beneficial not only to technical high school programs but also to general K-12 science classrooms.
- This study shows that the quantity and length of participation in an engineering integrated science curriculum matter for changing technical high school students' attitudes toward science.

support heavy industry (Chio, 2001). However, the socio-economic status of technical high school graduates has tended to remain lower than that of general high school graduates during the last 30 years. Consequently, the majority of those who enter technical high schools are mid-low achieving students at the point of middle school graduation. In particular, this group of students' interest in and attitude toward school science is less positive than their counterparts' in general high schools (Hur & Chae, 1997). They perceive that science is difficult and not useful for their future careers (Park, Park, & Kim, 2007). While many factors contribute to this result, one of the most critical is school science's lack of relevance to students' future careers (Galton, Gray, & Ruddock, 2003). In fact, South Korean technical high schools are required to teach the nationally recommended science curriculum, in which most of the science content is not selected for technical high school students' career readiness but for general high school students' college preparation (Bae & Geum, 2009). To improve technical high school students' interest and skills in science, redesigning a science curriculum that is more practical and relevant to technical high school students' future careers is crucial (Bae & Geum, 2009; Tseng, Chang, Lou, & Chen, 2011).

Engineering integration in K-12 science teaching has been spotlighted as a fruitful direction for improving student interest and achievement in science and engineering in recent international science education reform documents (e.g. NGSS Lead States, 2013; MEST, 2010; Morgan, Jones, & Barlex, 2013) and STEM studies (e.g. Baek et al., 2011; Koszalka, Wu, & Davidson, 2007; Lachapelle, Phadnis, Jocz, & Cunningham, 2012; Lee, Park, Kwon, & Seo, 2013). Considering the fact that technical high school students are pursuing careers in engineering-related fields, science teaching with engineering integration would be a very useful approach to improving these students' interest in science.

However, engineering integrated science teaching is a new pedagogical approach that has only recently been introduced in South Korea over the past three years. While there has been a widespread national movement in STEM education, engineering integration in secondary science classrooms rarely receives attention from science educators in South Korea (Bae & Geum, 2009; Baek et al., 2011; Kim & Kim, 2014; Lee et al., 2013). There are as yet no national guidelines or standards that define the scope of engineering education and the practical aspects of meaningfully implementing engineering integration in school science classrooms. To better support technical high school science teaching that should be relevant to the students' interests and future careers, we need more resources and empirical evidence to suggest effective ways of implementing engineering integrated science teaching and further supporting teachers' curriculum development (Kim & Kim, 2014; Kwon & Ahn, 2012).

In this study, we propose a framework for an engineering integrated science (EIS) curriculum. We also develop and implement two EIS curricula based on the framework to help first-year technical high school students improve their interest in science as well as their understanding of engineering practices. The primary purpose of this study was to investigate the impact of the curriculum on the students' attitudes toward science and perceptions of engineering practices. In particular, we were curious about how the quantity and length of EIS curriculum participation affect students' attitudes toward science. Most of the STEAM education curriculum that has been funded and developed by national grants in South Korea has been implemented for short periods such as a semester or less. However, recent studies about the impact of engineering integrated science curricula in South Korea often report that a short period of implementation (less than a semester) has no impact on students' science self-efficacy (an important construct of students' attitude toward science) (e.g. Sung & Na, 2012). Based on the results, this study therefore discusses the relationship between the length of EIS curriculum and its impact on students' attitudes toward science. This study also discusses challenges and advantages to teaching engineering in high school science classrooms in order to clarify the practical aspects of implementing an engineering integrated science curriculum in technical high school settings. The specific research questions that guided this study were:

1) How did the engineering integrated science curriculum affect the first-year technical high school students' attitudes toward science?

2) How did the different lengths of EIS curriculum participation affect the first-year technical high school students' attitudes toward science?

3) How did the engineering integrated science curriculum affect the first-year technical high school students' perceptions of engineers and engineering?

THEORETICAL FRAMEWORK: ENGINEERING INTEGRATION INTO SCHOOL SCIENCE CURRICULA

The necessity of engineering integration into technical high school science classrooms

Secondary students' lack of interest in science is a common phenomenon in many developed countries (e.g. Bennett & Hogarth, 2009). However, the situation is more serious among secondary students in South Korea (KICE, 2013; OECD, 2009). Even worse, technical high school students in South Korea who will pursue careers in STEM have less positive attitudes toward science compared to their counterparts in general high schools (Hur & Chae, 1997). Most technical high school students perceive that science is a very difficult subject that is not useful to their future careers (Park et al., 2007). To improve technical high school students' interest and skills in science, positive school science experience that is practical and relevant to the students' future careers is crucial (Tseng et al., 2011).

One of the major purposes of the recent national STEM education effort is to improve South Korean students' interest and confidence in science disciplines (MEST, 2010). Researchers in South Korea have advocated the necessity of science curriculum reform for technical high school programs that should be more relevant to the students' future careers, not only to improve students' interest in science but also their career aspirations in STEM-related fields (Bae & Geum, 2009). However, technical high school students do not get enough attention from STEM educators and policy makers, whose primary interest is attracting high-achieving students to STEM-related careers. Furthermore, under the current "one size fits all" national science education curriculum policy for all secondary students, technical high school students spend their science lesson time learning science content knowledge that is not relevant enough to their career preparation. Moreover, science lessons are strictly taught as a separate discipline from other engineering and technology courses without collaboration between science and engineering discipline teachers (Bae & Geum, 2009). Under the current situation, technical high school students hardly recognize the relevance of school science to their future careers, and consequently their interest in science might decline sharply.

Considering the fact that technical high school students are pursuing careers in engineering-related fields, science teaching with engineering integration would be a very useful approach to making school science relevant. In fact, engineering integration in K-12 science teaching has been spotlighted as a fruitful direction for improving student attitudes toward and achievement in science and engineering (e.g. Baek et al., 2011; Koszalka, Wu, & Davidson, 2007; Lachapelle, Phadnis, Jocz, & Cunningham, 2012; Lee, Park, Kwon, & Seo, 2013). Integrating engineering with school science is a potential and inevitable direction for reforming current technical high school science practices, particularly to improve students' interest and confidence in school science and career readiness in STEM fields.

Practical principles for engineering integration into school science curricula

Recently, STEM integration has gained national notice not only as a way to prepare students for 21st century STEM careers but also as a way to promote STEM literacy for all (e.g. KISTEP, 2014; MEST, 2010). Particularly in science education, engineering integration into the science curriculum is recommended by many international science education reform documents as a useful potential pedagogical approach to preparing future STEM workers (NRC, 2009; NRC, 2012; NGSS Lead States, 2013). For example, *A Framework for K-12 Science Education* (NRC, 2012) in the U.S. stated the importance of engineering inclusion in science education: "Engaging in science and engineering should help students see how science and engineering are instrumental in addressing major challenges that confront society today" (NRC, 2012, p. 9). Based on this framework, a recently released national document, *Next Generation Science Standards in the U.S.* (NGSS Lead States, 2013) includes "Engineering and technology and application of science" as one of four science disciplines. The main goal of this movement to include engineering in K-12 science classrooms is not merely to add engineering to school subjects but to integrate engineering *with* school subjects, particularly science and mathematics (Moore, Tank, Glancy, & Kersten, 2015).

Researchers have provided further compelling rationale for the integration of engineering into science classrooms. This includes: 1) improvement of knowledge and skill acquisition in science and engineering disciplines (e.g. Apedoe, Reynolds, Ellefson, & Schunn, 2008; Kwon & Park, 2009); 2) increased scientific literacy and problem solving skills (e.g. Brophy, Klein, Portsmore, & Rogers, 2008); 3) student interest in and positive attitudes toward engineering and engineering-related careers (e.g. Hirsch, Carpinelli, Kimmel, Rockland, & Bloom, 2013; Koszalka et al., 2007; Lachapelle et al., 2012; Lee et al., 2013); and 4) development of positive self-efficacy and career aspirations in science and engineering (e.g. Burgin, McConnell, & Flowers III, 2014).

While there has been a widespread international movement toward integrating engineering into school science curricula, there is no consensus about the scope of engineering integration in science classrooms (Brophy et al., 2008; Cunningham & Carlsen, 2014; Moore et al., 2015). For example, the NGSS define the scope of engineering integration with science as "engineering design." The authors of the NGSS stated, "It is important to point out that the NGSS do not put forward a full set of standards for engineering education, but rather include only practices and ideas about engineering design that are considered necessary for literate citizens" (NGSS Lead States, 2013, Appendix I, p. 3). "Engineering design" has been repeatedly mentioned as one of the core practices of engineering in many STEM education-related documents and studies (e.g. Guzey, Tank, Wang, Roehrig, & Moore, 2014; Kwon & Park 2009; NRC, 2009). For example, the *Engineering in K–12 Education* (NRC, 2009) highlighted the importance of engineering design in terms of its usefulness for teaching the central tenets of engineering practices: (1) highly iterative; (2) open to the idea that a problem may have many possible solutions; (3) a meaningful context for learning scientific, mathematical, and technological concepts; and (4) a stimulus to systems thinking, modeling, and analysis (NRC, 2009, p. 4). "Engineering design" thus provides a pedagogical approach for how to present the core ideas of engineering practice in science classrooms (NRC, 2009).

"Engineering design" has been called by various terms in engineering education literature, including "engineering design cycle," "engineering design process," "design research model," and "engineering design challenge" (e.g. Billiar, Hubelbank, Oliva, & Camesano, 2014; Hjalmarson & Lesh, 2008). There are also many ways to describe engineering design. In a recent STEM integration study, Lee et al. (2013) suggested that engineering design has three distinctive cognitive steps: 1) Analysis - analyze the problem situation, 2) Synthesis – synthesize information to solve the problem, and 3) Application – apply the synthesized knowledge to design a solution. Similarly, Moore et al. (2013) summarized three common components of engineering design: 1) defining the problem and conducting background research, 2) planning and implementing an engineering design, and 3) testing and evaluating the design. While engineering design has component ideas and steps, it is not a fixed step-by-step procedure but rather a flexible process based on the problem solving context. The NGSS point out that the components of engineering design "do not always follow in order" and a problem-solver can "redefine the problem or generate new solutions to replace an idea that just isn't working out" (NGSS Lead States, 2013, Appendix I, p. 2).

In addition to "engineering design," there are more practical principles that are repeatedly mentioned in many STEM education documents for meaningful integration of engineering into science classrooms (Billiar et al., 2014; Brophy et al., 2008; Glancy & Moore, 2013; Guzey et al., 2014; Hjalmarson & Lesh, 2008; Moore et al., 2015; NRC, 2009; Roehrig et al., 2012). These include:

- Collaborative and teamwork context
- Incorporation of important science and engineering knowledge
- Engineering habits of mind including systems thinking, creativity, and ethics
- Realistic and relevant engineering problems

If engineering design is a core practice of problem solving, collaborative teamwork offers a context in which to practice the social aspects of engineering problem solving (Moore et al., 2015). Engineering is a "highly social and collaborative enterprise" in which the social interaction between engineers, clients, and others who have a stake in the engineering project is a crucial component of successful engineering design (NRC, 2009, p. 38). Thus setting the engineering project in a collaborative context is critical not only for improving students' collaboration skills but also for helping them to understand the nature of science and engineering (Brophy et al., 2008).

Third, incorporation of important disciplinary content knowledge is also a crucial component of meaningful engineering and science integration (NRC, 2009). However, the scope and valid methods of implementing this principle in real classrooms is never clarified in the STEM education literature. As Cunningham and Carlsen (2014) point out, in many secondary science classrooms, engineering design projects "rarely dig very deeply into the substantive, conceptual terrain that is shared by science and engineering" (p. 202). One of the most general and highly recommended pedagogical approaches to incorporating science and engineering disciplinary knowledge is to use "engineering design" as a culminating activity to provide contextualized opportunities in which students can apply developmentally appropriate science content knowledge to design solutions (e.g. Guzey et al., 2014; Moore et al., 2013).

Fourth, "engineering habits of mind" is also considered an essential component of defining meaningful engineering practice (e.g. Brophy et al., 2008; Moore et al., 2013; NRC, 2009). Engineering practice is closely related to scientific inquiry activities in many aspects (NRC, 2009). Both engineering design and scientific inquiry are problem-solving processes that require scientific reasoning skills in testing hypotheses and finding evidence. However, there are also a number of characteristic attributes that could distinguish engineering practice from general scientific investigation and ways of thinking (NRC, 2009). Researchers have identified problem solving skills and knowledge specifically required in engineering practice that are not always an indicator of authentic scientific investigation. These include "Systems thinking, creativity, optimism, communication skills and attention to ethical consideration" (e.g. NRC, 2009, p. 5; Moore et al., 2013). Such problem solving skills and knowledge are often called engineering thinking or engineering habits of mind.

Fifth, the engineering problem context should be realistic and relevant to student experience. Presenting realistic engineering problems motivates students to engage in engineering projects because "they see the purpose in engaging in them, not because of their future utility but because of their inherent value" (Glancy & Moore, 2013, p. 5). Engineering problem solving that is relevant to students' personal experience is also important because it offers a learning context where students can apply their personal knowledge and experience and gives students an opportunity to realize the benefits and consequences of engineering work in their everyday lives (Brophy et al., 2008; Burgin et al., 2014).

In this study, we developed two engineering integrated science curricula by considering the principles of engineering integration described above. The primary purpose of this empirical study was to find evidence of the positive impact of an engineering integrated science curriculum on students' attitudes toward school science and understanding of engineering practice.

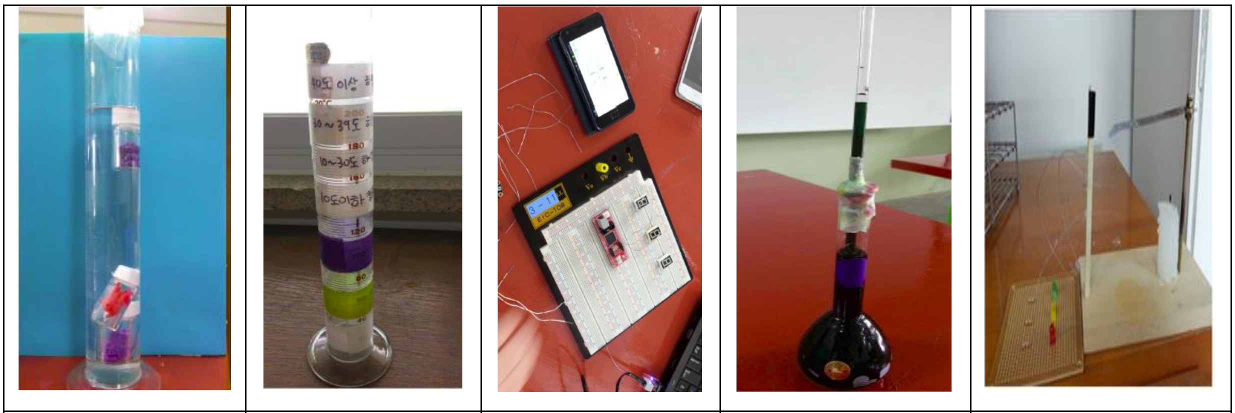
THE DEVELOPMENT OF ENGINEERING INTEGRATED SCIENCE (EIS) CURRICULA

Two engineering integrated science (EIS) curricula were developed based on the principles of implementing meaningful engineering integration in school science addressed in the previous section. The major objectives of these curricula were to help students understand the core practices of engineering design and scientific disciplinary knowledge of heat and heat transfer while participating in engineering design challenges. This concept was chosen because it is one of the important cross-cutting concepts presented in both science subjects and engineering and technology subjects in the technical high school curriculum in South Korea (Kim, Yoo, & Choi, 2012).

The engineering design topic in the first curriculum was to develop a temporal thermometer that could indicate a certain range of temperature of an object (solid, liquid, or gas) with minimal error. This curriculum was implemented to all first year students (N=420) in a technical high school for ten weeks (one hour class plus extra activity hours per week) during the Spring 2014 semester.

The second curriculum topic was to design an engineering device that could keep a penguin-shaped ice cube from melting. This curriculum was modified from Schnittka, Bell, and Richards (2010). Park, Nam, Moore, and Roehrig (2011) verified that this engineering curriculum helped students improve their scientific understanding of the concept of heat transfer. This curriculum was implemented only to half of the students who participated in the first EIS (experimental group, N = 190) for eight weeks during the Fall 2014 semester. The other half of the students (control group, N = 186) participated in general science inquiry lessons without engineering integration.

In both curricula, engineering design was used as a culminating activity that had three component ideas: 1) defining the problem and conducting background research about "heat" and heat transfer; 2) planning and implementing an initial prototype design; and 3) testing and evaluating the design. During the first step of defining the problem and conducting background research, students researched the different types of thermometers developed throughout history through an internet search and defined what specific problem they could solve with the given specifications (e.g. budget and time). For example, one group of students researched and decided to develop a thermometer similar to that developed by Galileo (Figure 1-(a)). They first defined problems that they could solve, such as finding the correct ratio for mixing different types of liquids in the small containers in the thermometer. Then the students planned and implemented an initial prototype design to find solutions (e.g. total mass of the small containers) that made the small containers float or sink at a certain temperature. Some of the student groups spent more time on developing an initial design due to their lack of science background knowledge. The teacher supported student groups if they needed content knowledge that was beyond the scope of the science topic, heat and heat transfer. Throughout the process of optimization, the students were testing and evaluating their designs and refining those designs based on the test results. Figure 1 shows samples of student work on multiple types of design solutions.



(a) Temperature change indicated by sink and float of objects in a container

(b) Temperature change indicated by thermochromics sticker

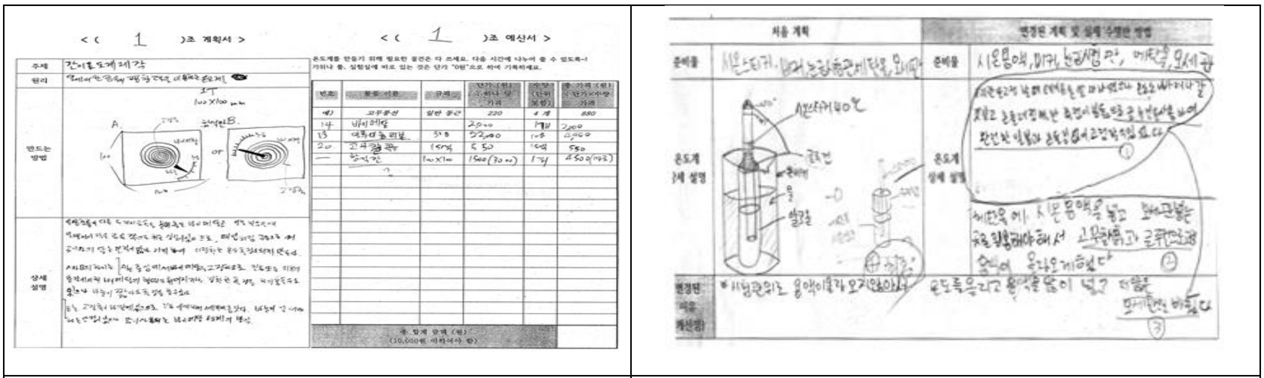
(c) Digital thermometer made by thermo-electric chips in electric circuits

(d) Temperature change indicated by the expansion of Isopropyl alcohol

(e) Air temperature indicated by LEDs in electric circuit connected to a bimetal

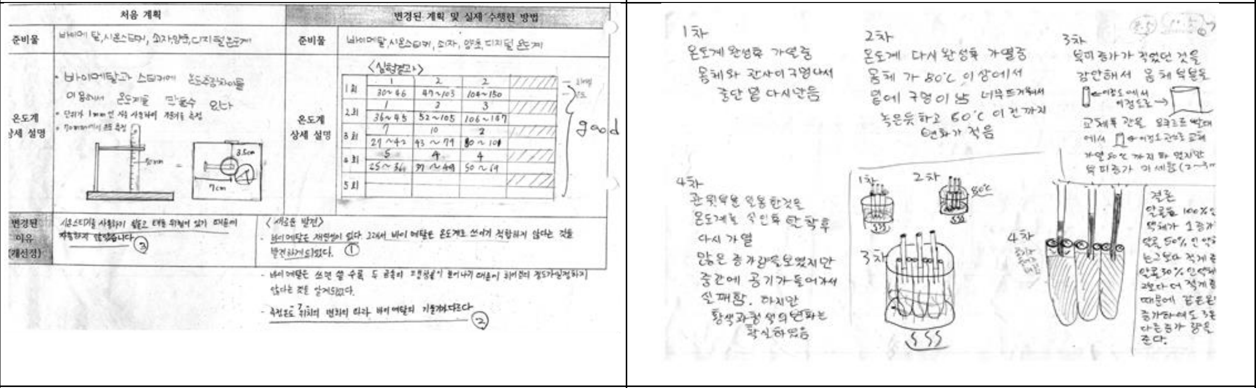
Figure 1. Five different types of thermometer design examples

In addition, three characteristics of engineering design were addressed: (1) taking into account specifications and constraints; (2) flexibility and iteration in the process of designing solutions; and (3) allowing multiple possible solutions (multiple types of design solutions) (NRC, 2009, p. 88-89). First, specification means that the usefulness and value of engineering design is dependent upon how much it satisfies a particular circumstance. For example, in the first engineering design, "measuring the temperature change of an everyday life object within 1°C error range" was the most important specification. In addition, limited time (ten weeks of class plus extra activity time), budget (Each group was limited to spending 10,000 Won [Korean currency], which is the equivalent of approximately 8 Euro [European currency] or 9 U.S. dollars), and accessible resources in the school science laboratory were constraints that students needed to consider to successfully finish their design solutions. Second, students were engaged in the iterative process of refining and optimizing their initial designs. Figure 2 shows students' records of refining their initial designs using different types of representation (e.g. drawing, making data tables). Third, students were allowed to choose multiple types of design solutions for their final product.



(a) Detailed drawing and description of ideas for optimizing initial design (left) based on the avaialble materials and budget planning (right).

(b) Detailed drawing and written description of the final design (left) and reflection of the unexpected order of the refining processes (right).



(c) Detailed drawing and description of ideas for modification of initial design (left) based on four trials of testing and results (right).

(d) Drawing and written description of the rationale behind four trials of the redesign process.

Figure 2. Different representations used during engineering design process

Students were assigned to teams of five and chose different roles within their teams: project manager, designer, recorder, material manager, and budget manager. Positioning students as members of an engineering team is important for improving their identity and confidence as engineers and eventually contributes to enhancing specific problem solving skills such as managing resources and budgets, effectively communicating and collaborating, recording processes and data, reporting test results, and so on. The teachers participated in the project not as leaders but as guides to support the growth of students' disciplinary knowledge.

To promote students' engineering thinking skills, we asked them to use various representation methods as means to record and share their ideas, such as creating drawings and written descriptions of their models, using different types of graphic organizers to compare benefits of different materials, and recording test results and providing verbal presentations about their products. Using multiple representations has been considered one of the critical problem solving skills in STEM disciplines (e.g. Hwang et al., 2007). Creating and using multiple representations is also considered a critical skill of engineering design. Research has shown that engineering model development involves increasing representational fluency (e.g. Moore et al., 2013). In other words, the quality of an engineering model is deeply related to the engineer's fluency in representation skills. By asking students to use different types of representation of their models, we expected an improvement in their engineering thinking skills, particularly in creating and using representation skills throughout the process of engineering model development (thermometer). Figure 2 shows student work samples from the first curriculum using different types of representations that present engineering thinking and problem solving skills in various phases of engineering design.

METHODOLOGY

This study utilized a mixed-methodology (Tashakkori & Teddlie, 1998) to investigate how engineering integrated science (EIS) curricula affect first-year technology high school students' attitudes toward science and perceptions of engineering. The effect of the EIS participation period on students' attitudes toward science was also investigated via experimental study design. The data came from three main sources: 1) a science attitude survey (SAS) instrument, 2) an engineering perception survey (EPS), and 3) semi-structured focus group interviews and four open-ended questions after the first curriculum implementation. The quantitative component of the study was designed to document the change in students' attitudes toward science as well as to understand the frequency of agreement rate on the positive impact of the program on students' understanding of engineering practice. The qualitative component of the study consisted of open-ended survey items and semi-structured focus group interviews (Berg, 1998) to develop a richer understanding of the students' experiences and perceptions of engineering practice.

School context and participants

The EIS curricula were implemented in science classrooms in a technical high school located in Seoul, South Korea. This technical high school offers 8 sub-programs for career readiness in different engineering and technology-related occupations (2 classes for each sub-program, total of 16 classes). Participant students' middle school GPAs ranged widely from 6% - 81%. Only 13 students were female (2.9% of total participants). Participating students worked in teams of four or five to design a temporal thermometer that met specifications and constraints given by the curriculum.

A total of 420 first year technical high school students (from all 16 classes) participated in the EIS curricula. The EIS curricula was taught by a female science teacher who had four years of science teaching experience at the time of the study. The teacher also participated in the EIS curriculum development process as well as the data analysis process to triangulate the results. The first EIS curriculum was implemented in chemistry classes for ten weeks (1 hour class time per week) during the Spring 2014 semester. To compare the short term (10 weeks during the first semester) and long term (18 weeks for two consecutive semesters) impact of the EIS curricula, we randomly divided the total students into two groups after the first EIS curriculum implementation. One group of students (control group, N=184) participated in regular science lessons without engineering integration, and the other group of students (N=190) participated in a second EIS curriculum during the Fall 2014 semester.

Data Collection

Science Attitude Survey (SAS)

A science attitude survey (SAS) instrument was developed by modifying the Science Attitude Survey from Hur and Chae (1997). Hur and Chae's was the only study that measured vocational/technical high school students' attitudes toward science in a South Korean context (to compare them to general high school students' attitudes toward science). Thus the content and wording in the SAS (Hur & Chae,

1997) was more relevant for this study than other SAS instruments used by more recent studies (e.g. Bennett & Hogarth, 2009). The SAS items were modified to make their content more relevant and clear to the current technical high school context and to remove some items that were not relevant to the purposes of this study. To establish the reliability of the SAS in this study, an internal reliability test was run on the Likert scale items using Cronbach's coefficient alpha (α = 0.893). The SAS includes 26 items organized by five categories: (1) Interest in science lesson, (2) Interest and confidence in science discipline, (3) Scientific disposition, (4) Value of learning science, and (5) Interrelationship between science, engineering and technology (items under each category are presented in Figure 3). Participants' agreement level on each item was measured on a five-point Likert scale system (strongly agree=5, agree=4, neutral=3, disagree=2, and strongly disagree=1) and converted to numerical data to compare mean scores. To investigate the effect of the EIS participation period on students' attitudes toward science, the SAS instrument was administered twice for both groups of students. For the experimental group (N = 190), pre and post SAS scores were collected before and after the long-term EIS curricula (first and second EIS curriculum). For the control group (N = 184), the SAS was first collected before the short-term EIS curriculum and then again after the regular science curriculum (short EIS curriculum and regular science lessons). Many studies about students' attitudes toward science, particularly involving the impact of curriculum interventions, show that short-term intervention would not affect student attitudes toward science (e.g. Sung & Na, 2012). Considering the real situation of the STEM innovative curriculum project in South Korea, which only supports a short period of time (average 3-4 months), we were curious whether a short-term curriculum intervention could have a lasting impact on student attitudes toward science after those students returned to regular science lessons. We believe collecting the SAS data this way simulated more realistic STEM education results in a South Korean context.

Engineering Perception Survey (EPS)

A survey to examine students' perceptions of engineering after the curriculum intervention was initially developed based on the five principles of engineering integration described in the framework section: (1) engineering design, (2) collaborative and teamwork context, (3) incorporation of important science and engineering knowledge, (4) engineering habits of mind including systems thinking, creativity, and ethics, and (5) realistic and relevant engineering problems. After the initial development of the EPS instrument, a face validity check was conducted by four experts in STEM education to determine the final items of the EPS. Based on the validity check, the researchers decided not to include items developed under the third category of "incorporation of important science and engineering knowledge," because the main purpose of the EPS was not to assess students' understanding of science content knowledge but rather to assess students' perceptions of engineers and engineering. The items under the first, second, fourth, and fifth principles were grouped as the item categories of: (1) Engineering Design, (2) Teamwork, (3) Engineering Habits of Mind, and (4) Engineers and Engineering in Society, respectively. Some of the items about engineering ethics were merged into the item category of: (4) Engineers and Engineering in Society depending on the intention of the items. This survey contained 27 Likert scale items that sought participants' agreement level, measured by a five-point Likert scale system (e.g., strongly agree, agree, neutral, disagree, and strongly disagree). The Likert scale items were analyzed by the frequency of the responses (percentage). In addition to the Likert scale items, four open-ended questions were used to obtain more insights into the participants' perspectives (Fontana & Frey, 2005). To establish the reliability of the

EPS, an internal reliability test was run on the Likert scale items using Cronbach's coefficient alpha ($\alpha = 0.945$).

The EPS survey items were grouped into four categories aligned with the engineering integration principles: (1) Engineering Design, (2) Teamwork, (3) Engineering Habits of Mind, and (4) Engineers and Engineering in Society (Figures 4-7). The first category, "Engineering Design," includes ten Likert scale items and one open-ended question ("What is your definition of engineering design?") to evaluate the impact of the program on students' understanding of the important component ideas of "Engineering Design" in three sub-categories: 1) Defining the problem and conducting background research; 2) Planning and implementing an engineering design; and 3) Testing and evaluating the design. The second category, "Teamwork," includes six Likert scale items and one open-ended question ("What does teamwork in engineering design mean to you?") to evaluate the EIS lesson impact on students' perceptions of the value of teamwork during an engineering project. The category of "Engineering Habits of Mind" includes five items focused on measuring the impact of the EIS lesson on improving the interest and mindset of engineering problem solving and students' perceptions of the relevance of the EIS curriculum topic to their everyday problem solving situations. The category of "Engineers and Engineering in Society" includes six Likert scale items to evaluate students' perceptions of engineers and social aspects of engineering such as ethics and the value of engineering in society. The other two open-ended questions were: "What was the most important thing you have learned from the EIS lesson?" and "What was the most meaningful thing you want to mention about the EIS lesson?".

The EPS instrument was administered to the entire group of students ($N = 328$) at the end of the first EIS curriculum. The average number of participants who answered the open-ended questions was 231. The EPS was not administered again at the end of the second EIS implementation because we found that comparing group differences was not meaningful for two reasons: (1) rich-enough qualitative data had already been obtained to show the positive impact of the EIS curriculum on students' perceptions of engineering, and (2) both qualitative and quantitative data analysis from both groups supported the positive impact of the EIS program on students' understanding of engineering practices. While collecting more data from the experimental group would make our conclusion more robust, we believe it would not change the current conclusion significantly. However, since we did not collect data after the long-term curriculum implementation, this could be a limitation of our study.

Focus group interviews

Five semi-structured focus group interviews were conducted after the initial EIS program to uncover vivid reflections about the students' experiences during the curriculum implementation. Twenty students from twenty different engineering design teams were purposefully selected to represent the diversity (gender, sub-program of each student enrolled) and academic levels of the student participants determined by school science tests. They participated in one of five focus group interviews with the first author of the study. Each interview lasted approximately 40 - 50 minutes. During the interviews, the students were asked about their experiences with engineering design. The interviews were taped and transcribed verbatim. Table 1 presents a timeline of the data collection process described above.

Table 1. Data collection instrument and timeline

Timeline	Control Group	Experimental Group
March 2014	SAS Pre Assessment	
April 2014-July 2014	First EIS Curriculum	
July 2014	Engineering Perception Survey Focus Group Interview	
August 2014-January 2015	Regular Science Lesson	Second EIS curriculum
February 2015	SAS Post Assessment	

Data analysis

Quantitative analysis

Likert scale item data in the Science Attitude Survey (SAS) instrument were converted to numerical data based on the five point scale system (strongly agree=5, agree=4, neutral=3, disagree=2, and strongly disagree=1). An independent T-test was run to compare scores between control and experimental group mean scores (Table 2). A paired T-test was run to examine the mean score difference between the pre and post SAS scores (Tables 3 and 4).

Likert scale items for the EPS were analyzed by the frequency of agreement levels. We decided that two criteria indicated the positive impact of the EIS program content addressed in each item: (1) the total frequency of “Strongly agree” and “Agree” responses on the item is higher than 60% of the total responses, and (2) the total frequency of “Strongly disagree” and “Disagree” responses on the item is lower than 10% of the total responses. If the frequency of each Likert scale item response met these two criteria, we decided that the response of the item indicated the positive impact of the program addressed in the item. To present the analysis results more clearly, the result table (Table 5) only presents the aggregated frequency of “Agree” (sum of the frequency of “Strongly agree” and “Agree” responses) and “Disagree” (sum of the frequency of “Strongly disagree” and “Disagree” responses).

Table 2. An independent samples T-test between each group’s SAS score at pre- and post-test scores

	Control group			**Experimental group**			**t**	**p**
	N	**M**	**SD**	**N**	**M**	**SD**		
Pre-test	184	3.33	0.50	190	3.40	0.50	-1.492	0.136
Post-test	184	3.42	0.56	190	3.58	0.51	-2.883	0.004*

*Note: * indicates that there is a significant difference between SAS score between the two groups (p < .05)*

Table 3. A paired T-test result of pre and post SAS scores within each group

	Control Group			**t**	**p**	**Experimental Group**			**t**	**p**
	N	**M**	**SD**			**N**	**M**	**SD**		
Pre	184	3.33	0.50	-1.708	.089	190	3.40	0.50	-3.488	.001*
Post	184	3.42	0.56			190	3.58	0.51		

*Note: * indicates that there is a significant difference between pre- and post-test SAS score within each group (p < .05)*

Table 4. Paired t-test results between pre and post SAS score within each group

Category		**Control**			**t**	**p**	**Experimental**			**t**	**p**
		N	**M**	**SD**			**N**	**M**	**SD**		
All Items	pre	184	3.33	0.50	-1.708	.089	190	3.40	0.50	-3.488	.001*
	post	184	3.42	0.56			190	3.58	0.51		
I. Interest in Science Lessons	pre	184	3.43	0.67	-1.279	.202	190	3.49	0.65	-2.529	.012*
	post	184	3.52	0.71			190	3.66	0.67		
II. Interest and Confidence in Science Discipline	pre	184	3.05	0.64	-1.886	.060	190	3.10	0.64	-4.018	.000*
	post	184	3.18	0.68			190	3.35	0.60		
III. Scientific Disposition	pre	184	3.53	0.65	-0.217	.828	190	3.59	0.67	-0.500	.617
	post	184	3.54	0.69			190	3.62	0.64		
IV. Value of Learning Science	pre	184	3.33	0.60	-1.674	.095	190	3.50	0.61	-3.185	.002*
	post	184	3.44	0.75			190	3.71	0.72		
V. Interrelationship between Science, Engineering, and Technology	pre	184	3.41	0.58	-1.682	.093	190	3.47	0.52	-3.444	.001*
	post	184	3.52	0.68			190	3.67	0.62		

*Note: * indicates that there is a significant difference between pre- and post-test SAS score within each group (p < .05)*

Table 5. The impact of EIS curriculum on students' perceptions of engineering

Category (number of items)	Sub-category (number of items)	Frequency (%) (N=328)		
		Disagree	Neutral	Agree
Engineering Design (10)	Defining problem and conducting background research (3)	7.84	31.39	60.07
	Planning and implementing an engineering design (4)	6.02	28.13	65.40
	Testing and evaluating the design (3)	5.15	25.39	68.76
	Category Average	6.34	28.30	64.75
Teamwork (6)		6.81	27.01	64.79
Engineering Habits of Mind (5)		9.05	31.87	59.08
Engineers and Engineering in Society (6)		11.47	37.41	51.04
	All Category Average	7.53	29.93	61.98

Qualitative analysis

Focus group interview transcripts and the data from open-ended question sections of the EPS were analyzed by interpretive and qualitative analysis methods utilizing combined content analysis (Patton, 2002). For these data, a coding scheme was established and validated by the three authors of this study. First the authors analyzed a smaller number of open-ended responses and interview transcripts from one focus group interview to establish coding categories and themes. Based on these initial categories and themes, all of the qualitative data were analyzed by the three authors to discern emerging patterns in the students' attitudes toward science and perceptions of the impact of the EIS curriculum. To support the reliability of the analysis, qualitative analysis results from both interview and open-ended question data were peer reviewed; inter-rater reliability was above 87% for all categories and themes. By triangulating the data from the Likert scale items, open-ended survey questions, and interview analysis, we were able to gain valuable insight into students' attitudes toward science and perceptions of the EIS curriculum.

RESULTS

Students' attitudes toward science before and after the EIS curriculum implementation

The statistical analysis between control and experimental groups' SAS scores shows that there was a significant difference between the two groups after the EIS curriculum. Table 2 presents an independent samples t-test result between experimental and control groups' SAS scores before and after the EIS curriculum implementation. The t-test results before the implementation indicate that there was no statistical difference between the two groups' SAS mean scores before the EIS curriculum (p = 0.136 > .05). Thus we can assume that these two groups were homogeneous in terms of their attitude toward science before the curriculum implementation. The mean scores of the SAS between the two groups were statistically different (p = .004 <.05). In other words, the experimental group's post-test mean score was significantly higher than the control group's.

To further support this result, we ran a paired t-test within each group to find the statistical difference between pre- and post-test within each group. Table 3 presents a paired t-test result within each group, showing that the increase of the control group's SAS mean score was not statistically significant (p = .089 > .05), whereas the increase of the experimental group's score was statistically significant (p = .001 <.05). In other words, students who participated in the longer EIS curriculum (for two consecutive semesters eighteen weeks total) had more positive attitudes toward science after the program, whereas the group that only participated in the curriculum for one semester (ten weeks total) did not change their attitudes toward science.

Thus we concluded that the score increase in the experimental group after the longer participation was statistically significant as evidenced by both the paired t-test result (comparing pre-post test scores within each group) and the independent samples t-test result (comparing test scores between the two groups).

To obtain a deeper understanding of the group difference by each item, Figure 3 provides a visual overview of the two groups' mean scores from post SAS tests by presenting the post-test mean scores of each item listed under each category. There are five items that have a significant difference between pre- and post-test in both

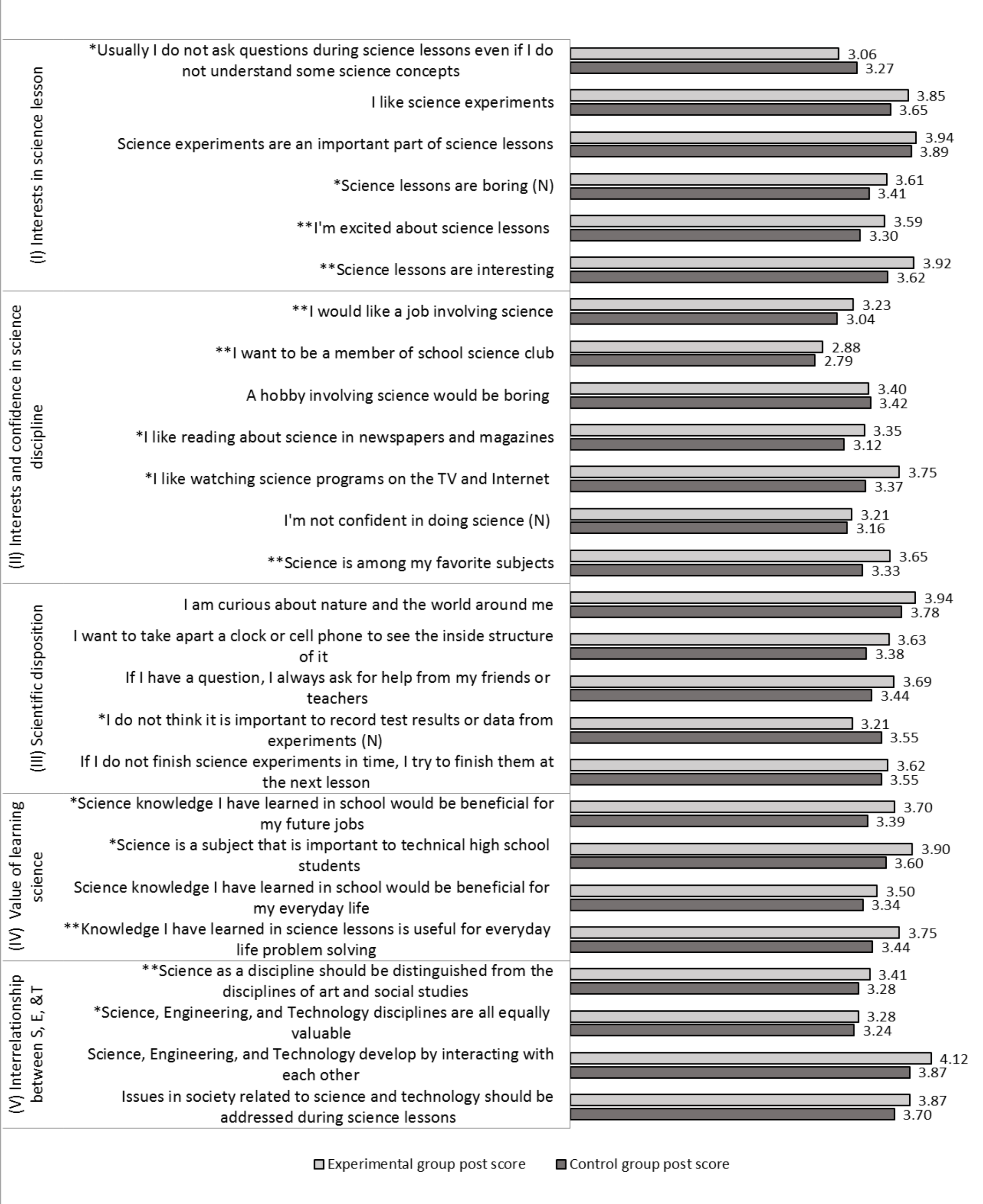


Figure 3. Post-test mean scores by each item in both groups

*Note: ** indicates that the mean score of the item increased significantly (p <.05) after the EIS curriculum in both experimental and control groups; * indicates that the mean score of the item increased significantly (p <.05) after the EIS curriculum in only the control group; '(N)' at the end of certain items indicates that the items were written as negatives.*

groups. Because these items were scattered in every category (and do not exist in "Scientific Disposition"), it is difficult to argue that the short-term participation had certain effects on students' attitudes toward science. There were also seven more items on which only the long-term participants agreed regarding the change in their perceptions of science. These items were scattered in every category including the "Scientific Disposition" category.

To obtain a deeper understanding of the positive impact of long-term program participation, Table 4 presents paired t-test results of pre- and post-test by category in both groups. According to the data, there is no statistical difference between pre- and post-test results in any category within the control group. For the experimental group, there are statistically significant score changes in most categories after the EIS lessons. Only one out of five categories, "Scientific Disposition," shows a statistically insignificant score increase after the EIS curriculum (p = .617 >.05). The other four categories show statistically significant score increases.

The positive results in certain categories indicate that long-term participation in the EIS curriculum positively influenced students' attitudes toward school science, particularly their interest in learning science at school ("Interest in Science Lessons") and perception of the value of science learning in their future job and everyday life applications ("Value of Learning Science"). In addition, the positive result in the category "Interest and Confidence in Science Discipline" implies that the EIS curriculum affected students' interest and confidence in science disciplines in general, not only in school science but also outside school. Furthermore, the positive result in the category "Interrelationship between Science, Engineering, and Technology" indicates that more students perceived that science is not a separate discipline from Engineering and Technology and that all of these disciplines are equally valuable and dependent upon each other in their development.

The only subcategory with no significant improvement was "Scientific Disposition" (p = .617 >.05). Considering the questions in this subcategory, which evaluated students' habits of mind while doing science, this result indicates that even long-term participation in the EIS curriculum did not have a significant impact on students' attitudes about doing science, such as perseverance in finishing a difficult scientific investigation with extra effort or willingness to investigate new scientific problems in everyday life situations.

Students' perceptions of engineering changed after the EIS curriculum

In this section, first we describe students' perceptions of engineering survey data based on the five main categories of the survey: (1) Engineering Design, (2) Teamwork, (3) Engineering Habits of Mind, and (4) Engineers and Engineering in Society. In addition, we obtained richer descriptions of the students' views and understandings of engineering that expand on the survey results from the qualitative data analysis. In the following section, we describe students' perceptions of engineering that emerged from both quantitative and qualitative analysis of the data.

Overview of the data

Table 5 provides an overview of the EPS results by each category and sub-category. Overall the results meet the two criteria that indicate the positive impact of the EIS lessons on students' understanding of engineering practice: (1) 60% or higher agreement frequency and (2) 10% or lower disagreement frequency. We decided that the result of the category "Engineering Habits of Mind" indicates the positive impact of EIS because the agreement rate (59%) is close enough to the first criteria and disagreement rate (9.05%) meets the second criteria. The only category that did not meet this criteria as an impact of EIS lessons was students' understanding of "Engineers and Engineering in Society." In the following sections, detailed explanations of the patterns obtained from analysis of the results are described by category.

Engineering Design

Students' perceptions of "Engineering Design" were examined via ten survey items categorized into three sub-categories: 1) Defining the problem and conducting background research, 2) Planning and implementing an engineering design, and 3) Testing and evaluating the design*.* Table 5 presents the overall results of the engineering perception survey for this category. While there are differences between the sub-categories, overall, more than 64% of the students agreed that EIS lessons positively impacted their perceptions of engineering design. Only about 6% of students disagreed about the ability of the curriculum to change their perceptions.

Figure 4 presents students' agreement, neutral, and disagreement rate for each item. The third sub-category, "Testing and evaluating the design," has the highest "Agree" rate (68.76%) on average compared to the first sub-category, "Defining the problem and conducting background research" (60.07%). This result shows that considerably more students (about 10%, *N* = 33) agree that the EIS lessons helped them understand the ideas in the third sub-category more than in the first sub-category.

To examine the students' perceptions of the definition of engineering design after the EIS lessons, we also analyzed 231 written responses on the survey and focus group interviews. We found that students' perceptions of the definition of engineering design can be summarized into ideas they emphasized in their responses: "Engineering design is a process of…": (1) collaboration (43%, *N* = 99), (2) problem solving (21%, *N* = 49), (3) refining and optimizing a prototype (13%, *N*=30), (4) pursuing efficiency in managing budgets and resources (13%, *N* = 30),

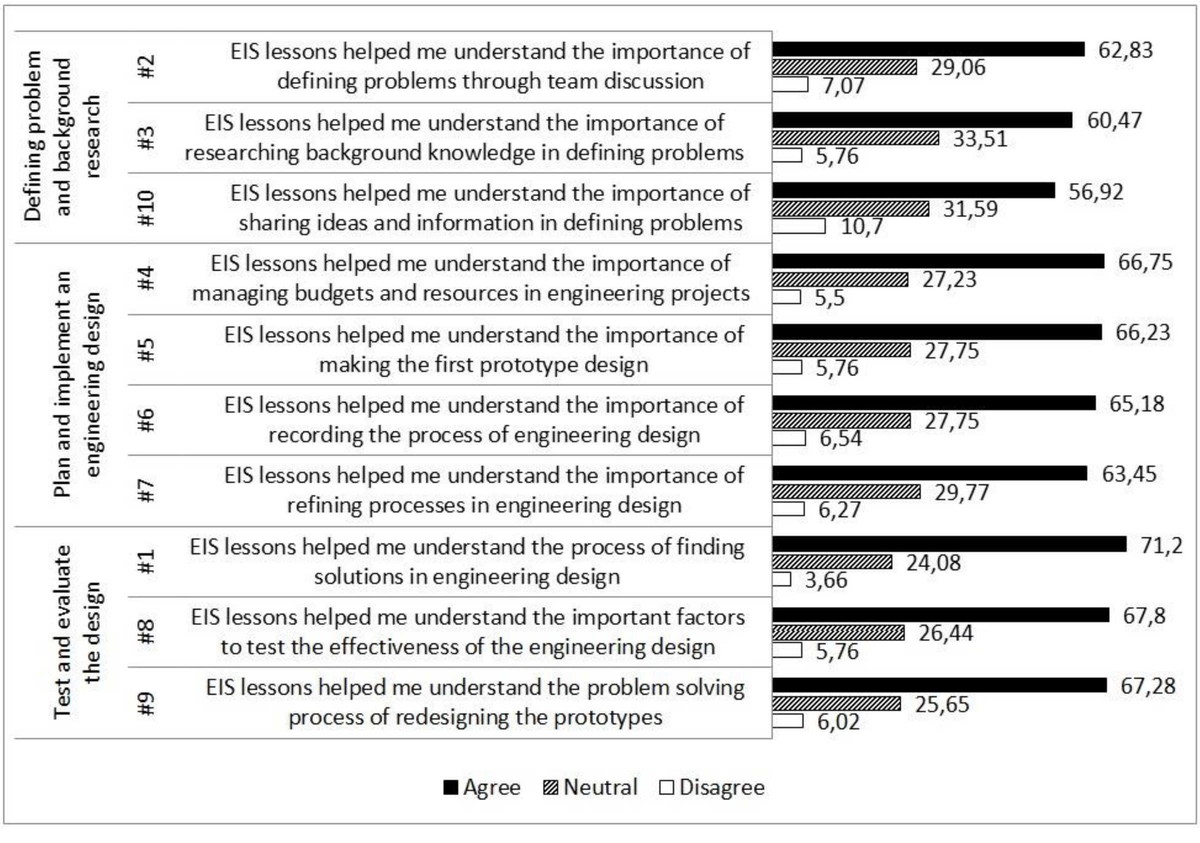


Figure 4. Change in students' perceptions of engineering design

and (5) searching for information and resources (10%, $N = 23$). The most frequent definition of engineering design was "collaborative working process" (43%). The students were impressed by the teamwork and collaborative climate during engineering design. We further describe their perceptions of collaboration in detail when we discuss the second category of the survey, "Teamwork," in the following section.

Students also perceived that engineering design is a process of problem solving. The students who emphasized this idea in their descriptions of engineering design focused on the fact that problem solving requires special thinking skills to analyze possible variables causing both errors and success in the design as well as creativity to overcome limitations of the given material.

The other students emphasized one of the component ideas of "engineering design" described in the literature (e.g. Moore et al., 2013): refining and optimizing a prototype (13%, $N = 30$), pursuing efficiency in managing budgets and resources (13%, $N = 30$), and searching for information and resources (10%, $N = 23$). Interestingly, the component idea of "testing and evaluating the design" was rarely mentioned in students' descriptions of engineering design. Overall, most of the students who responded to the open-ended question perceived that engineering design is a collaborative problem solving process that requires special thinking skills and is characterized as an iterative design process.

Teamwork

Effective teamwork is an important aspect of desirable engineering practice (NRC, 2009). The scope of students' perception change about the importance of teamwork and collaboration during engineering practice was examined via the six items addressed in Figure 5.

Overall, more than 64% of the students agreed that EIS lessons positively impacted their perceptions of the importance of teamwork during engineering projects. Only about 7% of students disagreed about the positive impact of the lessons. Among the items, the question about students' perception of the importance of communication skills between team members has the highest agreement rate (70.16%), whereas the item about the importance of collaboration between team members in engineering projects has the lowest agreement rate (60.21%).

In addition to the survey results, students' perceptions of the definition of "Teamwork during Engineering Projects" emerged from the analysis of 259 written responses on the survey. We found that students' definitions of "Teamwork during

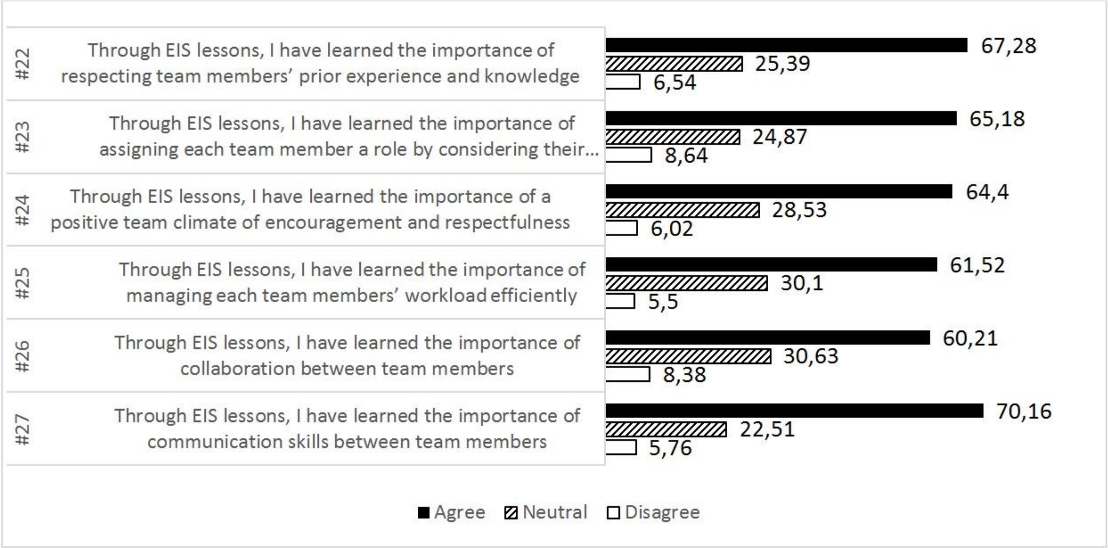


Figure 5. Students' perception change about teamwork during engineering projects

Engineering Projects" can be summarized into three broad ideas: (1) collaboration based on a strong relationship between team members (66%, $N = 171$), (2) effective communication between team members (22%, $N = 57$), and (3) fulfilling an assigned role faithfully (12%, $N = 31$). First, 66% of students perceived that a strong relationship between team members is a fundamental component of effective teamwork after the EIS lessons. These students mentioned that they had learned the importance of strong relationships in engineering projects through positive teamwork experiences in which team members encouraged each other and respected other members' ideas. As one of the students stated, "[From EIS lessons], I improved my skill of collaboration in a teamwork context and learned that we can solve a problem by respecting team members' ideas and opinions." About 20% of the students mentioned the importance of communication skills for effective team collaboration. They reflected that the engineering project in the EIS lesson was most meaningful in terms of developing their own communication skills. One of the students commented, "I have learned about how to communicate with my team members effectively and respectfully. The project experience helps me reflect my weakness in communicating my ideas with other team members."

The students also perceived that communication skills were important components of engineering projects in terms of a means through which to share knowledge. They believed that sharing information, knowledge, and resources was very important for successful engineering projects and that a proper level of team members' communication skills ensured this process. 67.28% of students agreed with item #22 (Figure 5) asking about the importance of respecting team members' prior experience and knowledge. In addition, about 10% of the students explicitly stated that sharing information, knowledge, and resources was very important for successful engineering projects. Some of the students' statements included: "I think respecting and sharing our experience and knowledge is important for successful engineering design" and "I have learned that respecting other's ideas and learning from each other are important for our team's success." In addition, about 12% of the students mentioned the importance of each member's faithfulness in team collaboration and fulfilling their assigned role. These results suggest that most of the students perceived teamwork as a fundamental component of engineering design because it provides not only a context for building strong relationships between team members and personal communication skills, but also because it offers an opportunity to fulfill an assigned role as a team member and makes them feel that they are a valuable part of the project team.

Furthermore, the improvement of students' understanding of the importance of collaboration during engineering practice is also evidenced by an analysis of the responses to two open-ended survey questions: "What was the most important thing you have learned from the EIS lessons?" and "What was the most meaningful or impressive thing you want to mention about the EIS lessons?" The most frequent responses (56%, $N = 102$ out of 181) to these questions were related to "understanding of the importance of teamwork and collaboration during engineering practices." In other words, more than half of the students reflected that collaborative teamwork was the most meaningful experience they obtained from the EIS lessons.

Engineering habits of mind

Questions in this category were focused on measuring the impact of EIS lessons on the improvement of interest, knowledge, and skills related to engineering problem solving and students' perception of the relevance of the EIS curriculum topic to their prior knowledge. Figure 6 presents the engineering perception survey on this category. Overall, more than 59% of the students agreed that EIS lessons positively impacted their interest, knowledge, and skills related to engineering

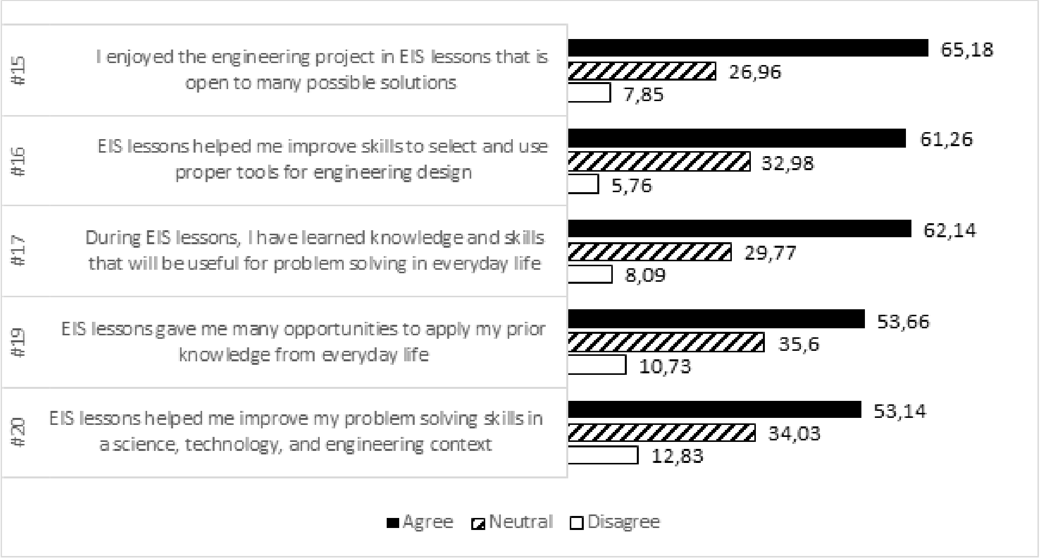


Figure 6. Students' perception change about engineering habits of mind after the EIS lessons

problem solving.

Figure 6 shows that the item asking about the context of engineering projects that allows students to develop multiple solutions has the highest agreement rate (65.18%). The students also positively perceived that the EIS curriculum was helpful for improving their knowledge and skills for problem solving in everyday life situations (62.14%) and skills for selecting and using proper tools for engineering design (61.26%). Students' written responses to an open-ended question also support these positive results. On an EPS survey question asking 'what meaningful things you have learned from the EIS curriculum,' about 22% of the students (N = 57, of 258 total responses) explicitly mentioned that they enjoyed the engineering problem solving context and were becoming more interested in engineering. These students mentioned that they had enjoyed the context in which they could try out the ideas their team members proposed and that the freedom of choosing any methods and solutions made them focus more on the process. About 19% of the students (N = 48) also mentioned that the EIS curriculum enhanced their knowledge and skills involving the materials and tools used to solve engineering problems. In particular, about 20% of the students (N = 52) emphasized that the EIS curriculum helped them improve their problem solving skills in everyday life situations. However, the items about "problem solving skills in a science, technology, and engineering context" (53.14%) and "application of prior knowledge from everyday life" (53.66%) have a lower agreement rate.

Engineers and engineering in society

Questions in this category evaluated students' perceptions about their confidence as engineers, understanding of what engineers do, and social aspects of engineering such as ethics and the value of engineering in our society. Figure 7 presents the engineering perception survey on this category. Overall, more than 51% of the students perceived that EIS lessons positively impacted their understanding of engineers and engineering in society in general, but the average agreement rate of this category was lower than the other categories in the engineering perception survey (61.98%).

Figure 7 shows that the item asking about the EIS curriculum impact on students' understanding of issues and challenges faced by engineers has the highest agreement rate of response (59.01%). This result reflects that the students had experienced multiple challenges that they had not expected before the engineering

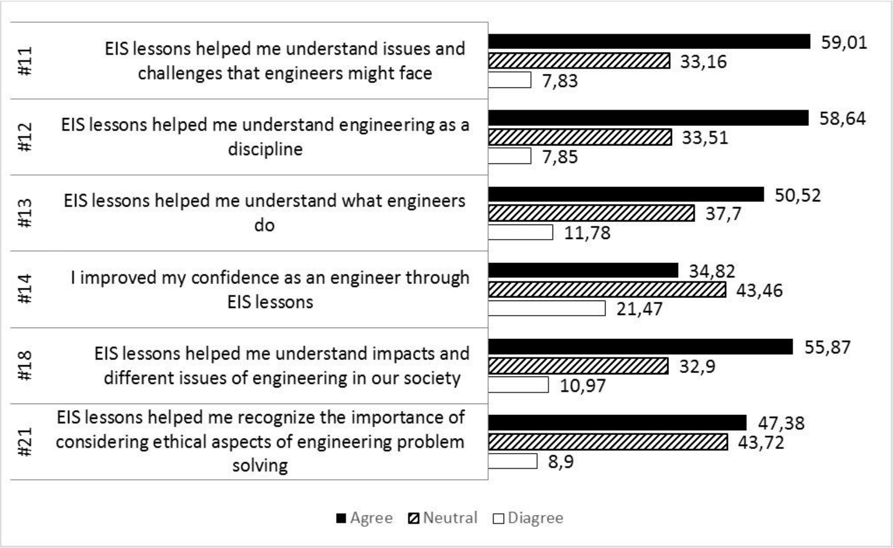


Figure 7. Students' perception change about engineers and engineering in society after the EIS lessons

project and believed that engineers might confront similar issues and challenges in their own work. In the following excerpt, students express the challenges that they experienced during the engineering project:

> Student A: Why is it so difficult to make even a temporal thermometer?
> Student B: I agree! Doing this is much more difficult than just thinking of its design.
> Teacher: What specific problems do you have?
> Student A: The liquid is not coming up to the straw. We believe that we followed all the directions we found from the internet. We sealed the container to prevent air leaking and we put the correct type of liquid inside it, and so on.
> Teacher: Can you guys describe how the liquid comes up through the straw?
> Student B: If the container is heated, the liquid inside of it will expand its volume by the heat.
> Teacher: How about gas inside of the container? Which one will increase its volume more than the other? Liquid or gas?
> Student C: Yes that is it! We need to consider both.
> Student A: There is no mention of that on the internet. I guess we need to recalculate the volume.

As this excerpt shows, students were confronted by many challenges that they did not expect before they started the project. While some of the groups overcame the challenges by themselves, many of them needed some kind of teacher support to solve these unexpected challenges. In the following excerpt, which is drawn from the focus group interview, one of the students also shared his opinion about an unexpected challenge that his group faced:

> Interviewer: What was the difference between your thinking about engineering design before and after the engineering project participation?
> Students (all): It was way more difficult than we expected.
> Interviewer: What particular aspect of engineering design was most difficult for you?
> Student D: At the beginning of the design, I thought it would be easy because the design we chose was a simple alcohol thermometer.

> However, when we finished our design, we realized that even putting a correct scale on the straw requires a very precise skill that engineers developed.

It appears that the challenging experiences during the engineering project negatively affected the students' confidence, as only about 34% agreed that they had improved confidence as an engineer through the EIS curriculum. The average agreement rate of this item (34.82%) was much lower than the average agreement rate of this category (51.04%) as well as of the whole survey (61.98%).

In addition, the agreement rate of question #21 about the ethical aspects of engineering (47.38%) was also lower than the average agreement rate of this category and the whole survey. This result suggests that compared to other items, the EIS lessons had a less positive impact on students' understanding of the ethical aspects of engineering in society. However, it is assumed that this result occurred partially because of the level of seriousness and sensitivity of the EIS topics in society. Developing a thermometer is considered less serious and sensitive in terms of ethical aspects in engineering products compared to the issues related to bio-chemical or environmental engineering topics such as GMO food, stem cells, or developing alternative energy sources to reduce pollution.

Furthermore, it appears that students developed a general sense of how engineering is different from other disciplines (item #12, 58.64%) and the issues and impact of engineering in our society (item #18, 55.87%). Qualitative data analysis results also show that students developed a more engineering-oriented mindset as a result of the EIS lessons. In the following excerpt, students explicitly state that the EIS project affected their thinking and viewpoints about engineered products they use every day:

> Interviewer: After the EIS lessons, is there any change in terms of your attitude and ideas when you look at any type of engineered product?
> Student E: What materials are in the product.
> Student F: How engineers came up with the idea to design the product.
> Student G: It would have been much more difficult than we expect to make that simple product.
> Student H: I changed my viewpoint about engineered products from consumer (product user) to engineer (product developer).

Overall, the agreement rate of this category was lower than the other categories in the engineering perception survey, particularly in the items asking about students' confidence as an engineer and understanding of ethics in engineering. However, a considerable number of students (a little less than 60%) agreed about the positive impact of the program on their understanding of engineering as a discipline, engineering as a career, and issues and the impact of engineering in society.

CONCLUSION AND DISCUSSION

Conclusion

The primary purposes of this study were to investigate how an EIS curriculum affects technical high school students' attitudes toward science and understanding of engineering practice. Overall, the results show that the EIS curricula positively affect students' understanding of engineering practice and attitudes toward science. Importantly, the positive impact on attitudes toward science was only guaranteed when the students participated in the EIS curriculum for a long enough period of time. In this study, the experimental group that participated in two EIS curricula for a total of 18 hours over two consecutive semesters changed its attitude toward science after the program, whereas the control group that only participated in one

EIS curriculum for a total of 10 hours over one semester did not change its attitude toward science. In other words, a short-term EIS curriculum implementation might not result in a statistically significant impact on students' interest in and attitudes toward science.

Compared to the effect of long-term participation on attitudes toward science, the EIS curriculum positively impacted students' understanding of engineering practice even after the first curriculum implementation (10 hours during the first semester). Overall, the engineering perception survey (EPS) results from both groups meet the two criteria that indicate the positive impact of the EIS lessons on students' understanding of engineering practice: (1) 60% or higher agreement frequency (61.98%) and (2) 10% or lower disagreement frequency (7.53%). The majority of students agreed that they had a better understanding of the engineering practices addressed in each EPS category as a result of EIS curriculum participation: Engineering design (64.75%), Teamwork (64.79%), and Engineering habits of mind (59.08%). The only category that did not meet this criteria was students' understanding of "Engineers and Engineering in Society."

EPS survey results in the first category, "Engineering design," show that a majority of the students perceived that the EIS curriculum positively impacted their understanding of three component ideas of engineering design: (1) defining the problem and conducting background research (60.07%), (2) planning and implementing engineering design (65.40%), and (3) testing and evaluating the design (68.76%). Interestingly, qualitative analysis results show that the majority of the students defined engineering design as collaborative problem solving.

The results in the "Teamwork" category had the highest agreement rate compared to the other categories (64.79%). In particular, more than 70% of the students agreed that they had learned the importance of communication between team members through the EIS program. Furthermore, qualitative data analysis shows that more than half of the students reflected that the collaborative teamwork was the most meaningful experience they obtained from the EIS lessons (56%, N=102 out of 181).

The agreement rate on the category "Engineering habits of mind" was high enough to support the positive impact of the EIS lessons (59.08%). However, the agreement rates in this category varied between the items (53.14%-65.18%). Students seem to perceive that the EIS curriculum was more helpful for improving their problem solving skills in everyday life situations (62.14%) than in a specific disciplinary context (science, technology, and engineering) (53.14%). They most enjoyed the context of engineering projects that is open-ended and allowed them to develop multiple solutions (65.18%).

The results of the category "Engineers and engineering in society" were less positive than the other categories (51.04%). The majority of the students agreed that they understood the perspective of engineering work in which engineers might confront multiple challenges while engineering design (59.01%), but interestingly only about 34% of students agreed that they had improved confidence as an engineer. It appears that the multiple challenges students faced during the engineering project negatively affected their confidence as an engineer. In addition, the item about students' understanding of the ethical issues of engineering in society had a lower agreement rate (47.38%) than the other items. Overall, the EPS results show that the EIS curriculum positively impacted students' understanding of the core practices of engineering. Multiple implications arise from the results in each category and item: (1) The EIS curriculum should be presented in a problem-based and student-centered learning context that gives students the opportunity for collaborative teamwork; (2) The level of content knowledge and challenges should be appropriate to students' abilities so they build confidence as engineers by successfully accomplishing a design solution; and (3) Engineering problems should be presented in a relevant and interdisciplinary context that could help students gain positive perceptions about engineering.

Discussion

Engineering integration with school science should be considered a potential pedagogical approach to improving technical high school students' interest and confidence in school science, positive image of engineering (Kim & Lee, 2010), and career readiness in an ever-changing engineering and technology field. The results of this study show that even a short period of participation in a well-designed engineering integrated science curriculum can help technical high school students understand core practices of engineering. More importantly, participation in an engineering integrated science curriculum for a long enough period of time (in this study, two different EIS curricula for two consecutive semesters) is a critical factor for influencing technical high school students' attitudes toward science.

A recent STEM education study in South Korea shows that a short-term engineering integrated science curriculum (3 months) did not change students' science self-efficacy, an important construct of science attitude (Sung & Na, 2012). In other words, to change students' attitudes toward science, they need to be exposed to a long-enough period of curriculum intervention. However, most of the innovative STEM education curricula in South Korea is for a short-term (less than one semester) intervention. This is mostly due to the fact that many of the STEM education research grants are for supporting short-term curriculum development and implementation. The results of this study suggest that we need more systemic support to implement longer EIS curricula in order to change secondary students' attitudes toward science, particularly for technical high school students.

There are two important factors that should be considered for reforming current science education practice in technical high school settings: First, we need systematic support to reserve enough time to implement authentic engineering integrated science curricula. Cunningham and Carlsen (2014) argue that, "If 'understanding engineering' is to be an educational goal, students will need experience doing complete engineering projects" to obtain a "coherent view of engineering as a discipline and a profession" (p. 202). Because of the interactive process of engineering design, an engineering integrated science curriculum would take more time than lecture-based science lessons. Thus the currently scheduled weekly science lesson hours in most of the technical high school curricula (2 hours/week) would not be enough to implement an authentic and student-centered EIS curriculum. To effectively manage current science lesson time for engineering integration, a smaller amount of science content should be recommended in the national science curriculum.

Second, developing new courses by integrating practical and important science, engineering, or technology disciplinary knowledge and skills for technical high school students' future careers should be considered critically by curriculum developers and national education policymakers. Under the current national curriculum, technical high schools teach STEM disciplines as separate courses. Thus students and teachers have difficulty conceptualizing the connections and relationships between important concepts and knowledge in each discipline. Therefore, developing an integrated curriculum that could suggest cross-cut concepts between these disciplines and pedagogical approaches for STEAM integration is necessary. In addition, the results of this study suggest that teamwork experience during the engineering project and the engineering context of "allowing multiple possible solutions" will have a positive impact on students' understanding of and interest in STEAM disciplines. Thus curriculum developers should consider these two factors as important components of pedagogical strategy for engineering integration.

In addition, more collaboration between science teachers and engineering or technology teachers should be recommended by national curriculum policy. Collaboration between different subject teachers is beneficial not only for sharing instructional time between disciplines but also for building a professional learning community between teachers where they support professional growth in STEM pedagogy and each other (Roehrig et al., 2012). Furthermore, science educators and policymakers need to pay more attention to current science education practice in technical high school settings to guide and aid current science teachers in developing high quality EIS curricula and collaborating efficiently with engineering subject teachers. The principles of engineering integration addressed in the Framework section can be used as effective criteria for developing a quality engineering integrated science curriculum.

Many studies support the finding that secondary students' attitude toward science is a critical indicator of their future career pursuits and retention in STEM disciplines in college. Thus, improving secondary students' attitude toward science is a critical issue not only in South Korea but also in other developed countries. Many studies show that school science experience is a critical factor that affects students' attitude toward science (Osborn, 2003). Engineering integration with science has been proven an effective approach to improve students' attitudes and achievement in STEM (e.g. Koszalka, 2007). This current study also shows that engineering integration is a fruitful pedagogical approach for improving students' attitude toward and perception of STEM disciplines. More importantly, the results of this study contribute to the international literature showing that an EIS curriculum is effective for improving this unique population of secondary students, technical high school students who are low-achieving in science and mathematics.

REFERENCES

Apedoe, X., Reynolds, B., Ellefson, M., & Schunn, C. (2008). Bringing engineering design into high school science classrooms: The heating/cooling unit. *Journal of Science Education and Technology, 17*(5), 454-465.

Bae, S-A & Geum, Y. C. (2009). Development model of activity-centered STEM education program in industrial and technical high school. *Korea Home and Career Education Journal, 15*(4) 345-368.

Baek, Y. S., Park, H. J., Kim Y., Noh, S. G., Park, J. Y., Lee, J., Jeong, J. S., Choi, Y., & Han H. (2011). STEAM education in Korea. *Journal of Learner-Centered Curriculum and Instruction*, *11*(4), 149-171.

Bennett, J., & Hogarth, S. (2009). Would you want to talk to a scientist at a party? High school students' attitudes to school science and to science. *International Journal of Science Education, 31*(14), 1975-1998.

Billiar, K., Hubelbank, J., Oliva, T., & Camesano, T. (2014). Teaching STEM by design. *Advances in Engineering Education, 4*(1), 1-21.

Brophy, S., Klein, S., Portsmore, M. & Rogers, C. (2008). Advancing engineering education in P-12 classroom*. Journal of Engineering Education, 97* (3), 369-387.

Burgin, S. R., McConnell, W. J., & Flowers III, A. M. (2014). 'I actually contributed to their research': The influence of an abbreviated summer apprenticeship program in science and engineering for diverse high-school learners. *International Journal of Science Education, 37*(3), 411–445.

Choi, K. M. (2014). Opportunities to explore for gifted STEM students in Korea: from admissions criteria to curriculum. *Theory into Practice, 53*(1), 25-32.

Choi, K-N. (2001). A study of relation between education policy of industrial high school and avoidance situation of industrial high school (Unpublished doctoral dissertation). Graduate School of Chung-nam National University, South Korea.

Cunningham, C. M., & Carlsen, W. S. (2014). Teaching engineering practices. *Journal of Science Teacher Education, 25*(2), 197-210.

Fontana, A., & Frey, J. H. (1994). Interviewing: The art of science. In Denzin, N. K., & Lincoln, Y. S. (Eds.), *Handbook of qualitative research* (pp. 361-375). Thousand Oaks, CA: Sage.

Glancy, A. W., & Moore, T. J. (2013). Theoretical foundations for effective STEM learning environments. Education Working Papers (1-1-2013), School of Engineering Education, Purdue University. Retrieved from http://docs.lib.purdue.edu/enewp/1

Guzey, S. S., Tank, K., Wang, H. H., Roehrig, G., & Moore, T. (2014). A high-quality professional development for teachers of grades 3–6 for implementing engineering into classrooms. *School Science and Mathematics, 114*(3), 139-149.

Hjalmarson, M., & Lesh, R. (2008). Engineering and design research: Intersections for education research and design. In A.E. Kelly, R.A. Lesh and J.Y. Baek (Ed.), *Handbook of design research methods in education: Innovations in science, technology, engineering, and mathematics learning and teaching* (pp.96-110). London: Routledge.

Hirsch, L. S., Gibbons, S. J., Kimmel, H., Rockland, R., & Bloom, J. (2013, November). High school students' attitudes to and knowledge about engineering. In 2013 IEEE Frontiers in Education Conference (FIE) (Vol. 2, pp. F2A7-12). IEEE.

Hur, M. & Chae, H-S. (1997). A Survey on attitudes related to science between the vocational high school students and the general high school students. *Korea Journal of Biology Education, 25*(1), 25-34.

Hwang, W. Y., Chen, N. S., Dung, J. J., & Yang, Y. L. (2007). Multiple representation skills and creativity effects on mathematical problem solving using a multimedia whiteboard system. *Journal of Educational Technology & Society*, *10*(2), 191-212.

Kim, K-S. & Lee, C-H (2010). Study on images of technical high school students toward 'engineering' through semantic differential method. *Journal of Korean Engineering Education, 35*(2), 25-42.

Kim, B. & Kim, J. (2014). Analysis of articles related STEAM education using network text analysis method. *Journal of Korean Elementary Science Education, 33*(4), 674-682.

Kim, S., Yoo, H., & Choi, K. (2012). An analysis of global issues and STEM education related topics in 2009 national secondary science curriculum. *Journal of Learner-Centered Curriculum and Instruction, 12*(2), 73-96.

Korean Institute for Curriculum and Evaluation (2013). Trends in International Mathematics and Science Study 2011; characteristics of Korean students' achievement in mathematics and science (Research report PIM 2013-1). Retrieved from http://www.kice.re.kr/board.do?menuNo=361&boardConfigNo=69&boardCategoryNo=27

Korea Institute of S&T Evaluation and Planning (2014). Issue analysis and plan establishment of creative science and technology human resource (Research Report, KISTEP 2014-006). Retrieved from http://www.kistep.re.kr/c3/sub2_2.jsp

Koszalka, T. A., Wu, Y., & Davidson, B. (2007, October). Instructional design issues in a cross-institutional collaboration within a distributed engineering educational environment. Proceeding of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education (pp. 1650-1657).

Kwon N. & Ahn, J. (2012). The Analysis on domestic research trends for convergence and integrated science education. *Journal of Korea Association of Science Education, 32*(2), 265-278.

Kwon, H. & Park, G (2009). Engineering design: the facilitator of science, technology, engineering, and mathematics education. *Journal of Korea Science Education Research, 3*(2), 207-219.

Lachapelle, C. P., Phadnis, P. S., Jocz, J., & Cunningham, C. M. (2012). The Impact of Engineering Curriculum Units on Students' Interest in Engineering and Science. In NARST Annual International Conference, Indianapolis, IN.

Lee, H., Park, K. S., Kwon, H. S., & Seo. B (2013). Development and implementation of engineering design and scientific inquiry-based STEM education program. *Korean Journal of Teacher Education, 29*(3), 301-326.

Ministry of Education, Science, and Technology (2010). Executive report to president Park Geun-Hye, Preparing creative human resources and advanced science and technology for Korea's future. Retrieved from http://www.moe.go.kr/web/110499/ko/board/view.do?bbsId=346&boardSeq=14388

Moore, T. J., Miller, R. L., Lesh, R. A., Stohlmann, M. S., & Kim, Y. R. (2013). Modeling in engineering: The role of representational fluency in students' conceptual understanding. *Journal of Engineering Education*, *102*(1), 141-178.

Moore, T. J., Tank, K. M., Glancy, A. W., & Kersten, J. A. (2015). NGSS and the landscape of *engineering in K-12 state science standards. Journal of Research in Science Teaching, 52*(3), 296-318.National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects.* Washington, DC: The National Academies Press.

Morgan, R., Jones, L. and Barlex, D (2013). New principles for design & technology in the national curriculum, E4E-education for engineering report. Retrieved from http://www.educationforengineering.org.uk/reports/pdf/e4e_report_feb2013.pdf

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

NGSS Lead States (2013). *Next Generation Science Standards: For States, By States.* Washington, DC: The National Academies Press.

Organization for Economic Co-operation and Development (2009). *Top of the class – high performers in science in PISA 2006*. Paris: Author.

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, 25(9), 1049-1079.

Park, S., Park, J., & Kim, B (2007). The relationship between technical high school student's learning style and science achievement. Research Report of the *Research Institute of Secondary Education at Gyungsang University*, 19, 143-165.

Patton, M. Q. (2002). *Qualitative research and evaluation methods*. Thousand Oaks, CA: Sage Publications.

Park, M. S., Nam Y., Moore, T. & Roehrig, G. (2011). The Impact of Integrating Engineering into Science Learning on Student's Conceptual Understandings of the Concept of Heat Transfer. *Journal of the Korean Society of Earth Science Education, 4*(2), 89-101.

Roehrig, G. H., Moore, T. J.,Wang, H.-H. & Park, M. S. (2012). Is adding the E enough?: Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics, 112*(1), 31-44.

Schnittka, C. G., Bell, R. L., & Richards, L. G. (2010). Save the penguins: Teaching the science of heat transfer through engineering design. *Science Scope, 34*(3), 82-91.

Sung, E-S., Na, S-I. (2012). The effects of the integrated STEM education on science and technology subject self-efficacy and attitudes toward engineering in high school students. *Journal of Korea Technology Education*, *12*(1), 255-274.

Tseng, K., Chang, C., Lou, S., and Chen, W. (2011). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education, 23*(1), 87-102.

Yuan, R. (2004). The globalization of science and engineering studies. Retrieved from, http://www.it.umd.edu/AS/EAST/cosmos.pdf

◆◇◆